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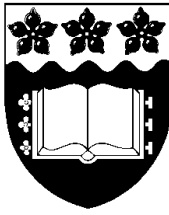
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**University of Wollongong
Economics Working Paper Series
2003**

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WP 03-11

August 2003

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Abstract: The Body Mass Index (BMI) provides a biased assessment of individual weight condition when there are substantial frame and muscle size deviations from the average for a given height. A method for overcoming this problem is presented. It allows an unbiased assessment of the individual level and degree of overweight and of the prevalence and intensity of overweight within the population.

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1. Introduction

The rates of overweight and obesity have been rising world-wide. In many countries these problems are now replacing smoking as the main public health issue. According to the National Heart, Lung, and Blood Institute (1998), the prevalence of overweight and obesity in the adult population of the United States has increased from 46 per cent in 1980 to 55 per cent in 1994. Finkelstein, Fiebelkorn and Wang (2003) have argued that the annual medical spending attributable to overweight and obesity is 9.1 per cent of all US national health expenditures. Furthermore, the morbidity and mortality associated with overweight and obesity generate a loss of output and well-being.

Some of the attempts to explain the spread of overweight and obesity are focused on technological developments that have made the production of food easier and cheaper (Cutler, Glaeser and Shapiro, 2003) and household and market work easier or more sedentary (Philipson and Posner, 1999; Lakdawalla and Philipson, 2002). Some other attempts emphasise the role of behavioural factors – addiction, rate of time preference and social norms, in particular. Following Becker and Murphy (1988) one may argue that if food items are addictive, consumers' expectations for long-run decline in the prices of these items might have led to a large increase in the consumption of food. Considering inter-temporally rational, non-addictive eating with trade-off between satisfaction from eating and risk to life posed by overweight, or underweight, Levy (2002) has proposed that the rationally optimal stationary weight exceeds the physiologically optimal weight and that the rationally optimal stationary level of overweight rises with the elasticity of utility from food and the individual rate of time preference. Hence, a rise in rate of time preference, *ceteris paribus*, may help explaining the rise in the prevalence and intensity of overweight and obesity (see also

Komlos, Smith and Bogin, 2002). Levy (2002) has also argued that the existence of social-cultural norms of appearance moderates the individual rational stationary level of overweight.

The international standard measure used by the medical profession for assessing weight condition and the prevalence of overweight and obesity is the Body Mass Index. This index is computed with externally measurable individual features and is equal to the ratio of i -th adult individual weight (W_i , in kilograms) to his, or her, height (H_i , in metres) squared

$$BMI_i = \frac{W_i}{H_i^2}. \quad (1)$$

Yet equally tall people may have different physiologically desirable weights due to: 1. differences in skeleton width, and 2. differences in muscularity. Hence, the assessment whether the individual weight is physiologically (or medically) proper lets the BMI be within an interval. According to the World Health Organization's definitions, BMI between 25 kg/m^2 and 29.9 kg/m^2 is overweight, and greater than, or equal to, 30 kg/m^2 is obese.

However, it is possible, on the one hand, that the BMI values of lean people with considerably large frame (wide skeleton) and muscles are beyond the normal interval's upper-bound and hence these people are reported as overweight. This possibility has been strengthened by the lowering of the upper-bound of the normal weight range from 27.3 kg/m^2 for women and 27.8 kg/m^2 for men to a unisex value of 25 kg/m^2 during the 1990s – a period that saw a tremendous increase in gym membership and attendance and in gym instruments at homes. It is also possible, on the other hand, that the BMI values of fat people with very small frame (narrow

skeleton) and muscles are within the World Health Organization's range of normal weight. Consequently, the aggregation of the individual results might lead to a biased assessment of the prevalence of overweight and obesity within the population.

Furthermore, the use of the BMI and ranges does not reveal the individual's level and degree of overweight, or underweight, and, subsequently, does not enable an accurate assessment of the intensity of overweight and obesity within the population.

The objective of this note is to construct an external weight measure that explicitly takes into account differences in frame and muscularity within a framework where the frame-width mean within a group of people with equal height as well as the individual physiologically desirable weight are not observable. Section 2 outlines a height-frame-muscle (HFM) approach for externally assessing weight condition. The HFM approach generates a reduced form of the individual weight equation whose parameters can be estimated by regression analysis with cross individual observations. The estimates of these parameters can be used to compute the HFM degree, prevalence and intensity of overweight presented in section 3.

2. The HFM Approach

The proposed HFM approach is based on the assumption that the unobserved physiologically desirable weight (W^o) may vary across people with equal height in accordance with the deviation of their frame and muscle size from the means in their height group:

$$W^o_i = \mathbf{a}H_i^2 + \mathbf{b}_1[F_i - \mathbf{m}_f(H_i)] + \mathbf{b}_2[M_i - \mathbf{m}_m(H_i)] \quad (2)$$

for $i = 1, 2, 3, \dots, N$ adult individuals of the same gender. Here, \mathbf{a} is a scalar denoting the medically optimal BMI value for a person with average frame and muscle size in

his, or her, height group; F_i is the frame size¹ of an adult individual i ; $\mathbf{m}_f(H_i)$ is the unobserved mean of the frame width within the group of people who are as tall as person i ; \mathbf{b}_1 is an unknown positive scalar indicating the effect of deviation from this mean on the individual's physiologically desirable weight; M_i is the muscle size of an adult individual i ; $\mathbf{m}_m(H_i)$ is the unobserved mean of the muscle size within the group of people who are as tall as person i ; and \mathbf{b}_2 is an unknown positive scalar denoting the effect of muscularity on the individual's physiologically desirable weight. The unobserved means of the frame width and the muscle size within the group of people who are as tall as person i are assumed to be proportional to height

$$\mathbf{m}_f(H_i) = \mathbf{g}_s H_i \quad (3)$$

$$\mathbf{m}_m(H_i) = \mathbf{g}_m H_i \quad (4)$$

where \mathbf{g}_f and \mathbf{g}_m are unknown positive scalars.

The deviation of the individual actual weight from his, or her, physiologically optimal weight is assumed to be given by a linear function of a vector, X_i , of *observed* deviations of the individual physical characteristics from the population average (age, chronic illness, disability, ethnicity, race, occupation, marital status, location, climate, etc.) and of a vector of *latent* deviations of some other individual characteristics from the average (e.g., rate of time preference, consumption preferences and mental disposition) constituting a zero-mean random disturbance \mathbf{e}_i

$$W_i - W^o_i = \mathbf{d}X_i + \mathbf{e}_i \quad (5)$$

¹ For instance, the Metropolitan Life Insurance Company has used the distance between the two prominent bones on either side of the elbow for assessing individuals' frame size (see <http://www.metlife.com/Lifeadvice/Tools/Heightnweight/Docs/frametable.html>). Elbow-width or wrist-width are highly correlated with bone and muscle mass.

where \mathbf{d} is the vector of the unknown coefficients indicating the effects of the observed deviations of personal characteristics.

The structural equations (2), (3), (4) and (5) lead to the following expression of the deviation of the individual actual weight from the medically optimal weight for a person of his, or her, height with average frame width and muscle size:

$$W_i - \mathbf{a}H_i^2 = -(\mathbf{b}_1\mathbf{g}_f + \mathbf{b}_2\mathbf{g}_m)H_i + \mathbf{b}_1S_i + \mathbf{b}_2M_i + \mathbf{d}X_i + \mathbf{e}_i. \quad (6)$$

3. The HFM measures of the degree, prevalence and intensity of overweight

The unknown parameters of the reduced-form equation (6) can be estimated, for adult males and adult females separately, with cross-section observations and non-linear estimation method. Consistently with its aforementioned interpretation and the World Health Organization's definition, \mathbf{a} can be set to be equal to the mid-value (22 for women and 22.8 for men) of the normal BMI range (19.1 – 24.9 for women and 20.7-24.9 for men) in constructing the dependent variable.

Subsequently, the individual computed physiologically desirable weight can be obtained by substituting the estimated values of $\mathbf{b}_1, \mathbf{b}_2, \mathbf{g}_f$ and \mathbf{g}_m into equations (2), (3) and (4). The deviation of the individual actual weight from his, or her, computed physiologically desirable weight (\hat{W}^o_i) is given by:

$$\Delta W_i \equiv W_i - \hat{W}^o_i = W_i - \mathbf{a}H_i^2 - \hat{\mathbf{b}}_1[F_i - \hat{\mathbf{g}}_f H_i] - \hat{\mathbf{b}}_2[M_i - \hat{\mathbf{g}}_m H_i] \quad (7)$$

where $\hat{\mathbf{b}}_1, \hat{\mathbf{b}}_2, \hat{\mathbf{g}}_f$ and $\hat{\mathbf{g}}_m$ are the estimates of $\mathbf{b}_1, \mathbf{b}_2, \mathbf{g}_f$ and \mathbf{g}_m , respectively and \mathbf{a} is equal to 22 for women and 22.8 for men.

If $\Delta W_i > 0$, individual i is overweight. The individual degree of overweight and the aggregate measures of the prevalence and intensity of overweight in a population can be computed as follows.

Individual Overweight Degree (IOD): The individual overweight degree is given by

$$IOD_i = \Delta W_i / \hat{W}_i^o. \quad (8)$$

Overweight Prevalence (OP): Let $D_i = 1$ if $\Delta W_i > 0$ and zero otherwise, then the measure of the overweight prevalence in a population of N adults can be expressed as

$$OP = \frac{1}{N} \sum_{i=1}^N D_i \quad (9)$$

and $0 \leq OP \leq 1$.

Overweight Intensity (OI): The proposed OI measure takes into account both the overweight prevalence and the individuals' overweight degrees within the surveyed population:

$$OI = \frac{1}{N} \sum_{i=1}^N D_i IOD_i = \frac{1}{N} \sum_{i=1}^N D_i \frac{\Delta W_i}{W_i^o}. \quad (10)$$

and $0 \leq OI \leq 1$ if $IOD_i \leq 1$ for every i with $\Delta W_i > 0$. It can be expected that $0 \leq OI \leq 1$ even when $IOD > 1$ for some individuals if there is a sufficiently large number of people with $IOD < 1$.

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